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FLIGHT SIMULATOR PLATFORM MOTION AND AIR TRANSPORT PILOT TRAINING

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Abstract

The influence of flight simulator platform motion on pilot training and performance was examined in two studies utilizing a B-727-200 aircraft simulator. The simulator, located at Ames Research Center, is certified by the FAA for upgrade and transition training in air carrier operations. Subjective ratings and objective performance of experienced B-727 pilots did not reveal any reliable effects of wide variations in platform motion design. Motion platform variations did affect the control behavior of pilots with no prior heavy aircraft flying experience. The effect was limited, however, to pitch attitude control inputs during the early phase of landing training. Implications for the definition of platform motion requirements in air transport training are discussed.

INTRODUCTION

The technology of manned flight simulation has seen substantial improvements over the past 50 years. Application of the technology to military and civil **aircrew** training needs has been prolific. However, the high cost of the technology, particularly in the areas of visual and motion simulation, has had a marked impact on its availability. Since the cost of a simulator can now exceed that of the aircraft, access to this very important training and checking tool has become increasingly restricted. The recent rapid growth and diversification of air carrier operations in the U.S. has provided a strong impetus for a better method of defining flight simulator design requirements. The relevance of simulator design characteristics to training needs rather than reliance on physical realism is **essential** to determining cost-effective design requirements. However, the influence of specific components of a simulator on training are rarely supportable with empirical research, relying almost exclusively on expert opinion. As expert opinion invariably differs on important issues, those involved in the design process are rarely provided with useful guidelines. One of the most controversial of existing simulator design issues is that of platform motion.

Under current regulations of the Federal Aviation Administration **all "simulators"** used for civil **aircrew** training within the U.S. are required to provide at least three degrees-of-freedom (DOF) of platform motion. Simulators used for initial, transition, and upgrade training and checking are required to have full six DOF platform motion systems. The requirement of platform motion is ostensibly based on the assumption that physical fidelity is highly correlated with training effectiveness. Since aircraft are capable of motion in all six axes (three translational, three angular), it is believed that the absence of motion in the simulator would significantly reduce its training effectiveness. Although no data exist to confirm or disconfirm this hypothesis for civil transport operations, training transfer studies conducted on general aviation and military training simulators do not support this assertion [see Waag (1) for a review]. While it is arguable that the motion systems in these studies were of the highest quality, the absence of motion effects across such diverse training environments and simulator equipment considerably weakens the case for requiring elaborate motion platform systems in flight simulators used for training pilots in **fixed** wing aircraft operations.

The purpose of this paper is to describe work in progress directed towards understanding the influence of motion platform systems on pilot behavior with particular emphasis on civil aviation

applications. Included in this effort is the development of an engineering design model which would provide the **system** designer with a tool by which motion platforms and their associated drive logic can be developed. Details of the model are beyond the scope of this paper but can be found elsewhere (Lee and **Bussolari, 1986**; Ormsby, 1974; **Sivan, Ish-Shalom, and Huang, 1982**). This paper will focus on results of two recent studies which evaluated the influence of motion platform variations on pilot performance and training. These studies represent the first attempt to evaluate the influence of platform motion on a simulator certificated under the FAA's advanced simulator program. Due to space limitations full details of the motion studies cannot be provided here. However, the essential elements will be given in order to provide an overview of this ongoing effort.

EXPERIMENT I

The first study in this research program was conducted to provide an opportunity to evaluate the utility of the engineering model and to investigate the impact of alternative limited motion design options for air transport flight simulators. Of particular interest was the relative influence of maneuvering and disturbance motion cues on pilot performance in tasks representative of those which are required during training and checking. Maneuvering cues are those which are a direct result of pilot control inputs while disturbance cues are the result of forces acting upon the aircraft independent of control inputs. Examples of the latter include turbulence motion and motion due to engine or structural failures. Since disturbance cues tend to be of a higher frequency the limited amplitudes of training motion platforms usually provide a high degree of physical fidelity. Maneuvering cues, by contrast, tend to be lower in frequency and thus cannot be fully provided by these motion systems. By systematically eliminating available maneuvering cues we hoped to assess the contribution of these cues to training effectiveness as well as to the perceived realism of the simulation.

METHOD

Participants

Eighteen air transport pilots currently flying B-727 aircraft participated as paid volunteers in the study. Of the eighteen pilots, three served in the Captain and 15 in the First Officer crewmember position. Experience in the B-727 ranged from 3 mos. to **7.5** years with an average of 2.4 years.

Apparatus

A Boeing 727-200 flight simulator certificated under Phase **II** of the Federal Aviation Regulations simulator requirements section (Part 121, Appendix H) was used for the study. The simulator, which is located at Ames Research Center, provides a full six DOF motion utilizing a non-linear, **adaptive** motion drive logic scheme. A **dusk/night** visual scene attachment provides a computer generated image of the out-of-the-cockpit scene to both Captain and First Officer positions. For this study only night scenes were provided.

Three motion platform conditions were compared in this study: the full six DOF motion required for Phase **II** simulators and two limited motion conditions. The latter platform motion conditions were provided by restricting the software logic driving the platform. For one of the limited motion conditions the six DOF system was reduced to two DOF: vertical and lateral translational motion. Inclusion of this condition in the test was to allow an evaluation of a system limited to providing vertical and lateral linear accelerations such as those associated with takeoff and landing roll accelerations and decelerations and lower frequency disturbance motion accompanying anomalies such as engine failure. The amplitude of normal platform excursions in these two axes was not limited. In the second limited motion condition, small amplitude vertical translation motion commonly called "special effects" were the only motion cues provided. These special effects include the following: runway touchdown bump, vibrations induced by runway **roughness**, buffets associated with flap, gear, and spoiler extension, Mach and stall buffet. **Maximum** leg extension with these effects was .25 in (.63 cm). These special effects were provided in

the full motion and two DOF motion condition as well.

Procedure

Six of the eighteen pilots were randomly assigned to each of three test scenarios. The three test scenarios were constructed to allow the evaluation of pilot performance in task conditions representative of those they would receive in the operational training environment. An additional criterion for task selection was the desire that significant pilot control activity be involved. This criterion was included to increase the probability of detecting motion platform effects if they did, in fact, exist. Each pilot was tested individually with the pilot-not-flying duties performed by a research pilot.

The three test scenarios were as follows: (1) engine flameout on takeoff subsequent to rotation (2) an **airwork** scenario consisting of steep turns, approach to stall, and standard turns with yaw dampers failed, and (3) an ILS approach and landing flown through a low-level, horizontal **windshear**. All scenarios were conducted in and around the simulated San Francisco International Airport environment. With the exception of the ILS approach and landing, all maneuvers were conducted in standard day, no wind, visual meteorological conditions. The simulated aircraft had a takeoff weight of 148,000 lbs (67,278 kilos). In order to standardize testing, fuel quantities were held constant throughout.

Prior to testing, pilots were provided with the opportunity to fly VFR approaches and landings with full platform motion in order to become familiar with the simulator environment. Pilots were not informed that motion platform conditions would be altered, only that the study's intent was to assess simulator fidelity issues. In all motion test conditions all normal procedures involving full motion operations were conducted so that pilots would not be made aware of any changes in platform functioning prior to testing. Those tested in the engine-out on takeoff scenario were required to perform two successive takeoffs from a standing start under each of the three motion conditions. Engine flameout onset time varied but always occurred within 5 sec following rotation. Engines No. 1 and 3 were failed randomly on successive takeoffs to reduce anticipatory control responses by the pilots. Pilots were instructed to maintain runway heading and level out at 2000 ft (610 m). The order in which the three motion conditions were tested was counterbalanced across the six pilots.

In the **airwork** scenario, the simulated aircraft was initialized at 250 KIAS and 15,000 ft (4573 m) MSL. The pilot was required to execute two successive steep turns followed by two successive approach-to-stall maneuvers with the aircraft in a clean configuration. Two standard rate turns with failed yaw dampers were then flown at an altitude of 33,000 ft (10,061 m) and 300 KIAS. Each pilot flew the **airwork** scenario once under each of the three motion conditions. The order of testing for motion conditions was counterbalanced across pilots.

Pilots assigned to fly the ILS approach and landing scenario began the approach at an altitude of 4000 ft (1220 m) and an airspeed of 220 KIAS. The pilots were initialized with an intercept course 30 deg off the localizer to SF0⁷'s runway **28R**. The ILS approach was flown manually by use of flight directors. Ceiling for the approach was 600 ft (183 m) with unlimited visibility at 500 ft (152 m). At this altitude a windshear was introduced which altered wind speed and direction from a 15 kt headwind to 10 kt tailwind at the runway surface. Wind was changed at a rate of -1 kt per 100ft (30 m) in speed and 36 deg per 100 ft in direction.

Measurement

Both subjective pilot ratings and objective simulator measurements were taken during the course of the study. The pilot ratings were taken after the completion of testing on a given motion condition within each scenario. The rating instrument consisted of six items each requiring a response on a 5-point scale. A rating of 3 on this scale indicated that the pilot felt the simulator to be very similar to the aircraft. Ratings lower or higher indicated that pilot believed the simulator to be unlike the aircraft. For example, a rating of 1 on control workload was given if the **simulator** control effort was much less than that of the aircraft, a 5 if the effort was much more than that of the aircraft. The six items addressed the following: Control workload in the

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scenario, control workload during configuration changes, general responsiveness of the simulator to control inputs, the utility of the simulator for training and checking, and an assessment of overall realism of the simulation. For all items, pilots were asked to base their ratings to the extent possible on experience with the aircraft. Objective measures of pilot and simulator performance were collected in real time at a rate of 15 samples per second. Aircraft state parameters such as airspeed, attitude, and altitude were sampled as were measures of simulator motion and pilot control inputs.

RESULTS AND DISCUSSION

The results of the subjective ratings of the simulator are depicted graphically in Figure 1. This figure shows the rating for each of the six categories averaged across the eighteen pilots and three test scenarios. In all categories and in all motion platform conditions the pilots rated the simulation to be very similar to the aircraft. No reliable differences in pilot ratings were found for the three motion conditions either within or across test scenarios for the six rating categories.

Aircraft state parameters and pilot control activity were analyzed to determine the effects of platform motion variations on pilot performance. Where successive trials of the same maneuver were executed data from these trials were averaged. Statistical analyses for a repeated measures design were conducted to determine whether differences among platform conditions were reliable. For the analyses each test scenario was treated as a separate experiment with experiment-wise Type I error set at a maximum of .10. Due to space limitations graphical exposition in this paper will be limited.

For the engine flameout scenario most of the data of interest occur shortly before and after the loss of power. Figure 2 shows the simulated aircraft mean absolute deviation from runway centerline as a function of motion platform condition 10 sec prior to and following engine flameout. No reliable differences were found. In order to evaluate motion effects on pilot control behavior the mean variance of the total rudder angle was calculated for this time period. In general, greater amounts of control activity will be reflected in an increased variance of control surface position over time. An analysis of pilot rudder control activity for the three motion conditions did not reveal any reliable differences.

Of the three maneuvers executed during the airwork scenario, data only on the stall maneuver will be presented here. This maneuver provided an opportunity to examine the pilots' ability to control the simulated aircraft during low airspeeds when the aircraft was operating with significantly reduced control stability. The data analysis window for the stall maneuver was defined as the period 10 seconds prior to and following the lowest airspeed attained. Figure 3 shows the mean variance in aircraft attitude during this period. Analyses of both aircraft pitch and roll angle variation were conducted for the three motion conditions. No reliable differences were found among motion conditions for either of these measures. Measures of pilot control activity during this maneuver also did not reveal any motion effects.

The instrument approach scenario was divided into two segments for the analyses. The first segment was the period during the approach starting at the time windshear was initiated (500 ft or 152 m) and ending 20 seconds later. This period will be identified as the approach maneuver segment in subsequent discussions. The mean absolute deviations of the aircraft from the glideslope and localizer are shown in Figure 4. [As a reference in interpreting this data note that the fuselage of the B-727 is about 12 ft (3.7 m) wide]. Although there appeared to be small differences in mean glideslope and localizer deviation as a function of motion platform condition, none of these differences proved statistically reliable.

The analysis window for the landing segment was defined as the last 10 seconds of flight. Aircraft state parameters and pilot control activity centerline were analyzed for the three motion conditions. As with the approach segment, variations in motion platform design had no reliable effect on any of the measures recorded.

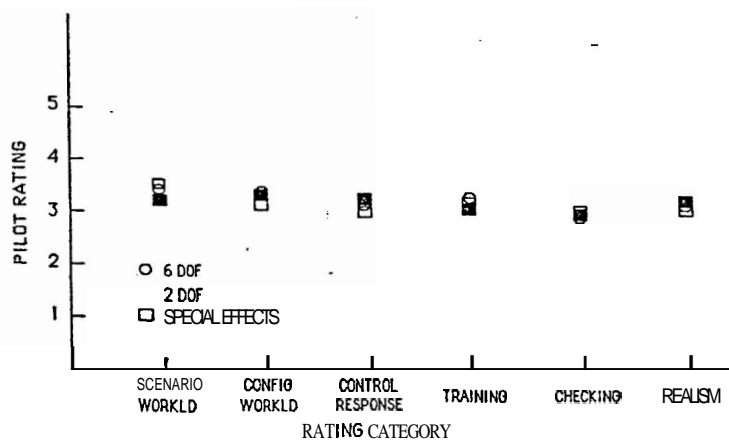


Figure 1. Pilot rating of simulator as a function of motion condition.

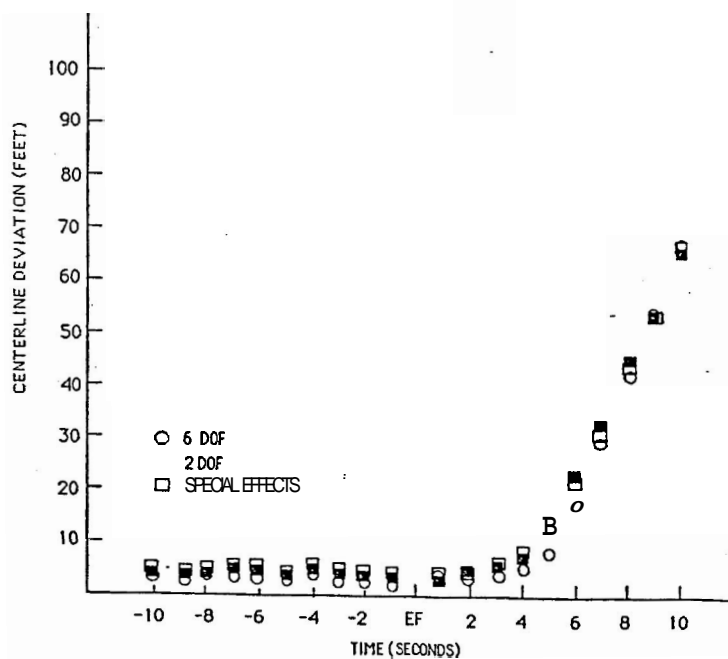


Figure 2. Aircraft centerline deviation prior to and following engine flameout (EF) as a function of motion platform condition, (N=6 pilots)

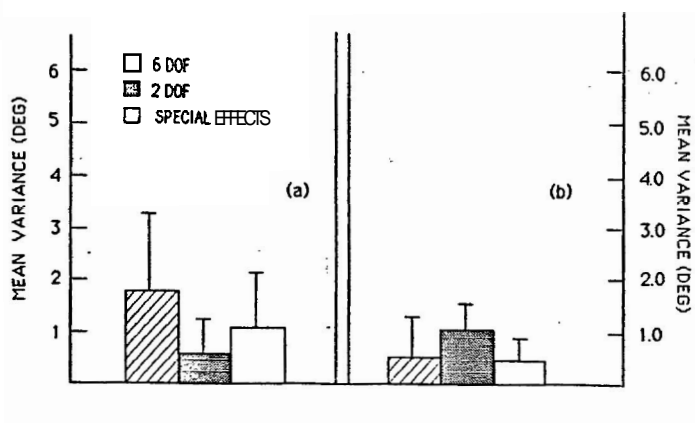


Figure 3. Mean variance of aircraft pitch (a) and bank (b) angle during approach to stall. (T-Bar=1 S.D., N=6 pilots)

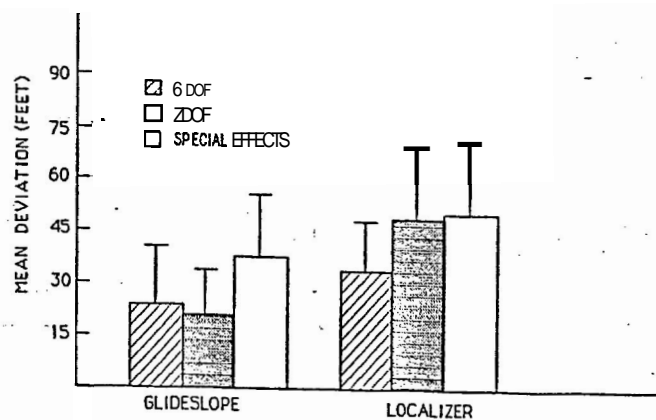


Figure 4. Mean glideslope and localizer deviation during the Instrument approach maneuver. (T-bar=1 S.D., N=6 pilots)

EXPERIMENT II

The absence of any reliable effects of motion platform design variations on pilot performance and subjective ratings would tend to support arguments for less complex motion systems, at least for the maintenance of skill. However, it is important to distinguish sensory cues which may support the performance of a well-learned skill and those which may influence its acquisition. In order to evaluate the generality of the findings of the **first** experiment, a second study was conducted to assess the impact of motion platform variation on the acquisition of flying skill in **air-**crews with no prior experience in this aircraft type.

METHOD

Participants

Sixteen air **transport** pilots served as paid volunteers in this study. Twelve were currently employed as commuter airline pilots flying twin engine turboprop aircraft, the remaining four were employed in local charter and training operations. Average age of the pilots was 31 yrs. (**range** of 24 to 46 yrs.) with total flying hours averaging 4,250 (range of **1200** to **11,000** hrs) of reciprocating engine and 900 **hrs.** (range of zero to 2,000 hrs) of turbine engine aircraft time. None of the pilots had prior experience with aircraft of the size used in large air carrier operations (such as the B-727).

Apparatus

The same B-727-200 flight simulator as employed in the first experiment was used in this study. However, only two motion conditions were evaluated. The full six DOF motion capability including special effects was contrasted with the motion condition providing special effects only.

Procedure

The sixteen pilots were divided into two matched groups of eight pilots each, one group for each of the two motion conditions. Matching of the groups **was** conducted to assure the greatest degree of comparability between groups prior to training. Matching variables were type of professional employment, experience in reciprocating and turbine aircraft, total instrument flying hours, and age. Subsequent t-tests revealed no reliable differences between the two groups on any of the selected matching variables.

Each pilot was provided with an introductory overview of the B-727 cockpit and general operating **characteristics**. Simulator familiarization consisting of 20 min. of general **airwork** was provided to give the pilot experience with the handling characteristics of the B-727. Ten visual takeoffs and landings were then conducted in the same environment as Experiment 1 with dusk conditions, unlimited visibility, and no wind. No visual approach aiding system was provided: Following the visual approach and landing training session, the pilots were required to execute five ILS approach and landings using the B-727 manual-flight **director** system. For these trials the simulated aircraft was initialized at altitude (4,000 ft.) in instrument conditions and vectored to intercept the localizer about 12 mi. from the runway. Weather conditions for the trials were a 600 ft ragged ceiling, 5 mi. visibility, and wind 280 deg at 15 kts.

RESULTS AND DISCUSSION

The same aircraft state parameters and pilot control inputs examined in Experiment I were analyzed in this study. Analyses of variances were conducted on each variable to determine whether the substantial design differences between the full six DOF and the limited special effects condition affected the learning and performance of approach and landing skill in these pilots. Analyses conducted on aircraft state parameters and pilot control measures revealed, with only one exception, no reliable effects of motion platform design on either the rate of skill acquisition or overall **performance**. The sole exception to this finding was a reliably ($F=4.86$, $p<.05$) higher variance in control column movement during the early visual landing training. Data for this period are shown in Figure 5. The effect was no longer present during the later instrument

training trials. The higher variance in control movement during landing with maneuvering motion present suggests that the pitch accelerations provided by the motion platform are affecting the control strategy adopted by the trainees early in the study. The effect did not extend to control wheel movements, however, despite considerable displacement during landing. As shown in Figure 6 the maneuvering motion cues present in the six DOF condition had no significant effect on aircraft roll control activity.

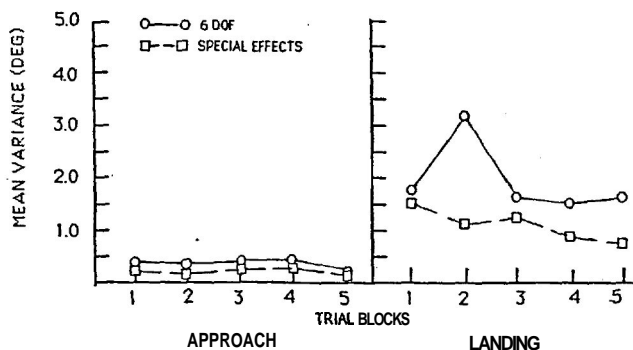


Figure 5. Mean control column variance during visual approach and landing trials (N= 16 pilots).

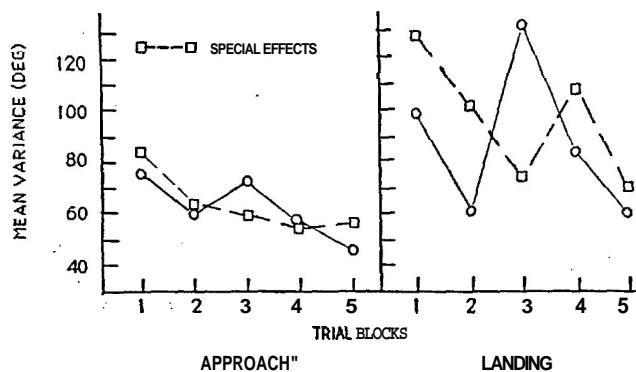


Figure 6. Mean control wheel position variance during visual approach and landing trials (N= 16 pilots).

DISCUSSION

The two studies reported here further demonstrate that determining simulator design requirements is not a simple matter of assessing the extent of physical **realism** the device provides. Aircraft handling characteristics, task conditions, and pilot experience can combine to influence the effectiveness of platform motion. Despite the wide application of this technology in current air transport training operations we found no evidence that, at least under the conditions reported here, experienced pilots perform differently in the absence of motion provided by complex platform systems. Further, subjective ratings of realism and simulator control responsiveness also were unaffected by the elimination of all maneuvering motion cues and virtually all disturbance motion cues. Apparently, minimal perturbations of the platform were **sufficient** to satisfy whatever the pilots perceived to be subjective realism.

The presence of a reliable effect of motion in the second experiment **would** support the belief that the **relatively** limited performance of a training simulator motion system can provide at least

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some useful motion cues and that the absence of motion effects in the first study was not due to inadequate motion system performance, per se. The limitation of the motion effect to pitch axis accelerations during landing training has implications for visual as well as motion system design. Many visual cues critical to landing are often degraded or absent in current operational systems and this fact may have increased the reliance of inexperienced pilots upon motion cues for aircraft control early in training. Whether enhancement of the visual scene would have nullified the influence of motion in this study is a matter for future research.

It is important that the studies reported here should be considered within the context of a training simulator evaluation for transport aircraft. The tasks selected for inclusion in the studies are representative of the types of tasks that a pilot would be required to perform during initial, transition, and recurrent training in this aircraft. No attempt was made to alter the normal operating characteristics of the aircraft simulated. The presence of visual, auditory, and tactile cues which would normally occur in the simulator training environment were provided. This study does not address the issue of whether motion platform cues affect pilot behavior under all conceivable conditions but only a sample of those conditions to which the pilot is normally exposed in simulator training. From the standpoint of normal training operations the subjective and objective data collected on the transport simulator motion study suggest that large, complex motion platform systems may not be necessary for either reasons of pilot acceptance or performance. For training in this type of aircraft: simulators with very limited motion capability may be adequate for training purposes. Further research on training transfer is needed to confirm this hypothesis, however.

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